3.8 Interface Modeling

Interfaces in composite materials play a major role in the determination of their mechanical and thermal properties. Consequently, it is important to have the ability to model interface behavior accurately. This is accomplished in **MAC/GMC** in one of two ways. The first is to define an actual interface region with its own constitutive behavior. In this way the influence of initial imperfections (flaws, voids, improper wetting, etc.) and induced interfacial damage (due to stress, environment, chemical reactions, etc.) may be incorporated into the micromechanical analysis of the overall behavior of the composite. The development of proper interfacial constitutive models is an active area of research, and **MAC/GMC**, through the use of its **USRMAT** routine, provides the researcher with a convenient tool for testing new and existing interfacial constitutive models.

The second approach to modeling the effect of imperfect (weak) bonding between two phases (e.g. a fiber and a matrix) is to assume that a jump in the displacement field at an interface may occur given certain conditions, while still maintaining continuity of the traction vector. In the spirit of Jones and Whittier [13] and Achenbach and Zhu [14] we have assumed the following flexible interface model.

$$\begin{bmatrix} (u_n^I = R_n \cdot \sigma_n^I) \\ (u_t^I = R_t \cdot \sigma_t^I) \end{bmatrix} \qquad if \qquad \begin{bmatrix} \sigma_n^I \geq \sigma_{DBn} \\ \sigma_t^I \geq \sigma_{DBt} \end{bmatrix} \tag{EQ 44}$$

$$\begin{bmatrix} (u_n^I = 0) \\ (u_t^I = 0) \end{bmatrix} \qquad if \qquad \begin{bmatrix} \sigma_n^I < \sigma_{DBn} \\ \sigma_t^I < \sigma_{DBt} \end{bmatrix} \tag{EQ 45}$$

where R_n, R_t, σ_{DBn} and σ_{DBt} are the interfacial normal and shear, compliance and debond stresses, respectively. Note, the implementation of the various forms for R_n and R_t described below will impact the definition of the concentration matrices, $\underset{\sim}{A}^{(\alpha\beta\gamma)}$ in the original **GMC** formulation or its counterpart in the reformulated version, see **section 3.1.**

This approach to debonding has been implemented in **MAC/GMC** in two forms. In the first, R_n and R_t are assumed to be constants that are independent of time. Therefore, when the time derivative of EQ. 44 is taken (as it is for implementation in the incremental formulation of **MAC/GMC**) the expression becomes,

$$\begin{bmatrix} (\dot{u}_n{}^I = R_n \cdot \dot{\sigma}_n{}^I) \\ (\dot{u}_t{}^I = R_t \cdot \dot{\sigma}_t{}^I) \end{bmatrix} \qquad if \qquad \begin{bmatrix} \sigma_n{}^I \geq \sigma_{DBn} \\ \sigma_t{}^I \geq \sigma_{DBt} \end{bmatrix} \tag{EQ 46}$$

Hence, the debonding is instantaneous, and immediately reaches its full extent. If R_n and R_t are chosen to be sufficiently large (as is customary), the stress at the interface will remain constant, with a value of σ_{DB} after debonding occurs.

In the second form, R_n and R_t are assumed to be functions of time. Thus we obtain

$$\begin{bmatrix} \dot{u}_n{}^I = R_n \cdot \dot{\sigma}_n{}^I + \dot{R}_n \cdot \sigma_n{}^I \\ \dot{u}_t{}^I = R_t \cdot \dot{\sigma}_t{}^I + \dot{R}_t \cdot \sigma_t{}^I \end{bmatrix} \qquad if \qquad \begin{bmatrix} \sigma_n{}^I \geq \sigma_{DBn} \\ \sigma_t{}^I \geq \sigma_{DBt} \end{bmatrix} \tag{EQ 47}$$

in lieu of EQ 46. The additional term present in EQ. 47 for both normal and tangential debonding is significant. If the time-dependence of R_n and R_t is chosen wisely, these additional terms will enable local unloading in the composite. For implementation in **MAC/GMC**, the following functional form of the time-dependence has been employed,

$$R(t) = \Lambda\left[\exp\left(\frac{\hat{t}}{\mathrm{B}}\right) - 1\right] \tag{EQ 48}$$

where $\hat{t}$ is the time since debonding, and Λ and B are functional parameters which characterize how the interface unloads.

Figure 5 shows a simple example to illustrate the differences between the two implementations of this debond model. The repeating unit cell used to generate the results shown in this figure, is IDP= 1 as illustrated in Fig. 9. As Fig. 5 shows, the results generated using both implementations of the debond model are the same until debonding occurs at an interfacial stress of approximately 15 ksi. At this point, the stress at the interface in the first implementation becomes constant, while, in the case of the second implementation, the slope of the interfacial stress verses applied strain curve decreases and then the interface begins to unload. The effect of the difference between the two implementations on the predicted composite stress-strain response is shown clearly in Fig. 5, where the softer composite response is a result of additional inelasticity in the remaining matrix subcells due to the local stress redistribution from the debonded subcells.

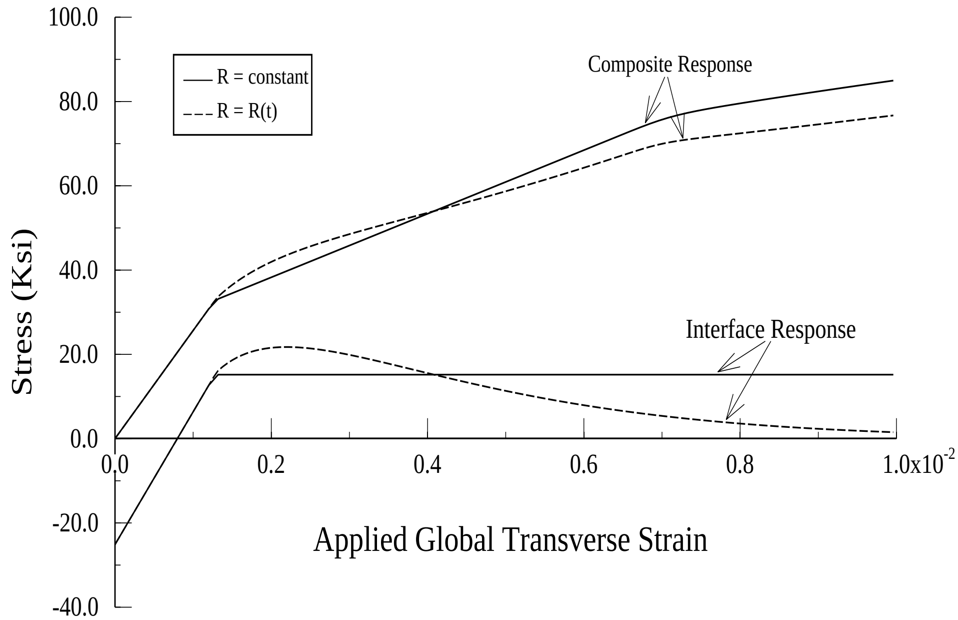

Figure 5. Simulated transverse behavior using the two implementations of the debond model in **MAC/GMC**.